Variable Vector Countermeasure Suit (V2Suit) for Space Habitation and Exploration

NASA Innovative Advanced Concepts Phase 1

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V2Suit for Space Habitation and Exploration

- Spaceflight adaptation countermeasure suit
  - Sensorimotor
  - Musculoskeletal

- Utilizes properties of gyroscopes to provide “viscous resistance” during movement
V2Suit Motivation

- No “down” in 0-G
  - Visual perceptions dominate
  - “Down” direction may change

- Physiological adaptation to weightlessness

- Perceptual and resistance benefits:
  - Sensorimotor adaptation
    - Earth G, Moon G, Mars G
  - Full-body, tactile perception
  - Musculoskeletal de-conditioning

The V2Suit facilitates human adaptation and performance during long-duration spaceflight


V2Suit Phase 1 Progress

- **U.S. Patent Application**
  - “Exoskeleton Suit for Adaptive Resistance to Movement”
  - Submitted: November 30, 2011

- **Media Coverage**
  - The Washington Post, txchnologist.com, \\, Space.com, Space-travel.com, plus others

- **Human-System Integration**
  - Form factor concept
  - Module placement
  - Interface with body/garment

- **Initial V2Suit Module Design**
  - Flywheel orientation and placement
  - Integration and packaging

- **Technology R&D**
  - Alternate uses
  - Key technologies
Human-System Integration
Placement of a V2Suit module on each arm and leg segment
Upper-Body Integration

Lifesize Mannequin

Upper Arm Module

Lower Arm Module

Power & Processing
V2Suit System Architecture & Design
V2Suit for Space Habitation and Exploration

- V2Suit System
  - Low-profile, wearable system
  - Network of sensors and actuators
  - Central power and processing

V2Suit System Architecture

V2Suit Modules
- IMUs
- Flywheels
- Motor controllers

Central Processing and Commanding
- V2Suit Module Orientation
- Parameterized “Down” Tracking
- Motor Commands
- V2Suit Module Pos., Vel.
- Resistance Magnitude
- Power

- IMU Data
- Flywheel rotation rate
- Flywheel gimbal rate

- Navigation
- Initialization
- Actuation
Generating Gyroscopic Torque

- Alternatives for a body-worn system
  - Single Axis Flywheel
    - Change in flywheel spin rate
    - Change orientation via body kinematics
  - Control Moment Gyroscope (CMG)
    - Variations in: spin rate, gimbal rate
    - Command torque direction and magnitude
    - Adds complexity
      - Slip rings & bearings

Multiple 2-axis CMGs have ability to provide desired torque direction and magnitude within a body-worn form factor

\[ \vec{\tau} = -\vec{\omega} \times \vec{h} \]
Gyroscopic Torque Parameters

Material:
Stainless steel,
\[ \rho = 7950 \text{ kg/m}^3 \]
\[ m = 0.0576 \text{ kg} \]
\[ I_x = 1.0443 \times 10^{-5} \text{ kg} \cdot \text{m}^2 \]

Variables:
- moment of inertia
- spin rate
- gimbal rate
to generate the desired torque

\[ \omega_g = \omega \]
\[ h = 0.00635 \text{ m} \]
(0.25 in.)
\[ \omega_s = h \]
\[ r = 0.01905 \text{ m} \]
(0.75 in.)

100 rad/sec = 954 rpm
Benchtop Concept Demonstration

- LabVIEW
  - Data Processing
  - Commanding

NI Controller

V2Suit Module
Prototype built from RC aircraft/helicopter components to demonstrate concept and develop technology roadmap.
Multiple control moment gyroscopes packaged with on-board IMU, motor controller, and power/communications interface.
Technology R&D
V2Suit Alternate Uses

- **Spacecraft Interior**
  - Sensorimotor
  - Musculoskeletal

- **Low-G EVA**
  - Stabilization
  - Orientation control

- **Exercise/Rehabilitation**
  - Movement trajectories
  - Posture stabilization

- **Industrial**
  - Keep-out zones
  - Safety zones

Platform Technology for Space- and Earth-based Applications
<table>
<thead>
<tr>
<th>System Attribute</th>
<th>Current State</th>
<th>Tech R&amp;D</th>
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</table>
| **Packaging**                | • Spin and gimbal motors  
• Slip rings, bearings  
• IMU  
• Motor controllers, comm. | • ~36 in³  
• COTS  
• Spin motors  
• Motor controllers  
• MEMS IMUs | • Micro motors  
• Slip rings  
• Vibration |
| **Navigation**               | • Position/Orientation Initialization  
• “Down” Tracking | • Kalman filter | • Body worn relative motion  
• Initialization  
• Temporal drift |
| **Control**                  | • Response time  
• Spin vs. gimbal rate | • > 1000 rpm spin rate  
• No gimbal motor  
• ~50 ms response delay | • Spin/gimbal coordination, respond to whole body movement |
| **Power**                    | • Steady state vs. transient  
• Operations duration | • 2 W steady state, 12 W spike  
(COTS components) | • Motor selection  
• Custom controllers  
• Battery sizing |
| **Human-System Integration** | • Wearability  
• Resistance magnitude  
• Perceptual artifacts | • Outer garment  
• Central power/cmd | • Don/doff time  
• Garment integration  
• Perceptual experiments |

Identify and assess risks with key system technologies through early-stage evaluations, prototypes and simulations.
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- **Human-System Integration**
  - Form factor and attachment points
  - Mannequin demonstration

- **Initial V2Suit Module Design**
  - CMG orientation and placement
  - Integration and packaging

- **Technology R&D**
  - Alternate uses: earth and space
  - Key technologies for future R&D